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Mandibular dentoalveolar reactions to rapid palatal expansion

INAUGURAL-DISSERTATION

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Hinweis auf geplante Publikation

Eine verkürzte Version der vorliegenden Dissertationsarbeit ist für eine Publikation mit dem Dissertanten als Erstautor geplant.

Für:

Meine Eltern Marianne und Viktor Meienhofer

1. Summary

AIM: This study aims to investigate the dentoalveolar reaction of the mandible concurrent to rapid maxillary expansion, registering both the differences of transversal dimensions and the changes in inclination of mandibular teeth.

MATERIAL AND METHODS: The casts of 28 Patients who underwent rapid palatal expansion as sole treatment were examined pre- and post-expansion (post-expansion: at least 6 month into retention). The distance measurements were made directly on the plaster casts for the upper and lower canines and first molars. The change in angle of the lower first molars was obtained by digitalisation of the casts and measuring on a cross-section through the first molars.

RESULTS: A low but significant ($p<0.001$) increase of the distance between the lower first molars (1.0mm ±0.63mm SD) was found and a significant increase ($p<0.001$) in lower first molars angulation (3.12° ±4.67° SD) was detected. Change of mandibular intercanine width was, however, not significant ($p=0.313$), and no correlation ($p=0.250$) between molar angle alteration and mandibular molar width increase was found.

CONCLUSIONS: The obtained results are comparable to previous reports, and for the first time these movements could be described with more accuracy by demonstrating a change in angulation. Although the observed increase was significant, the gain of such a small amount in width has very limited clinical relevance in terms of mesio-distal space improvement. Moreover, no association between width and angulation was found, demonstrating that these two effects do not necessarily have to appear combined.

2. Introduction

In 1728, Pierre Fauchard was the first to describe a slow expansion of the dental arch (Fauchard, 1728), and rapid palatal expansion was first introduced in the pioneering work of Emerson C. Angell in 1860 (Angell, 1860). Since then, maxillary expansion has been developed further and now rapid palatal expansion is a relatively simple orthodontic technique in the maxilla that is routinely applied to increase the transversal width of the maxilla. The indications for carrying out such a treatment are most commonly defined as unilateral or bilateral cross-bite, but other indications such as arch increase to obtain more space in a crowded situation have also been suggested (Je & Ashby, 2008).

2.1. Basic concepts about rapid palatal expansion

- ***Cross bite***

Transversal cross bite, especially the functional unilateral cross bite with a lateral shift from centric relation to centric occlusion, is a common malocclusion affecting up to 7% of children (Stöckli & Ben-Zur, 1994). It is usually already present in the primary or in the early mixed dentition. The maxilla shows a smaller or similar transversal width than the mandible. Along the centric path of closure of the mandible, the cusps would therefore first coincide owing to the maxillary restriction, and only with a lateral shift can a proper occlusion be found with a crossbite on side (Je & Ashby, 2008).

If not treated, this constant sliding can lead to a stimulated growth in the opposite temporomandibular joint, and the functional crossbite can develop into a real morphological asymmetry (Byrn et al., 1995).

- ***Expansion***

There are multiple approaches to expand the maxilla in the transversal dimension. Some appliances will only enlarge the dental arch, while others are able to increase the basal width of the maxillary bone. The choice over which appliance to be used depends therefore to a great deal on the defined aims of any individual treatment and its underlying cause.

Some appliances perform only on a dentoalveolar level with tooth movement that can be categorized as either a tipping or a bodily lateral shift of the teeth (or both), combined with alveolar bone remodelling. Most removable appliances like splints are meant to displace just the teeth without much basal effect, but some fixed appliances could be used to such a regime as well (Weyrich, Noss & Lisson, 2010).

If the aim is not only to alter the position of the teeth but also to reach a skeletal reaction, the magnitude of the force needs to be amplified for the following reason: The mid-palatal suture, being a zone of growth, can be targeted and its growth potential modified. With moderate to heavy orthodontic tension pressure, rupture of the suture is possible, and will lead to amplified growth in the suture. While it is literally impossible to determine what force is required to alter the growth pattern in the suture, clinical experience suggest that such forces can only be applied with a fixed orthodontic device, which can distribute the force to as many teeth as possible.

Like any other craniofacial suture, the mid-palatal suture becomes more and more inter-digitated and tortuous with increased age (Melsen, 1975). For that reason, therapeutically induced basal changes will occur at a young age more than in adolescents, and in later stages of life the suture often has to be opened with surgical methods (Angelieri et al., 2013).

There is a certain consensus that in order to reach the greatest possible skeletal effect the forces must be high in the beginning to open the suture, and the stretching must be quick. The underlying rationale for this is that the teeth need time to move inside the bone through alveolar bone remodelling, i.e. resorption and apposition of new bone. If sutural expansion is quick, there will not be enough time for the teeth to move and the effect will be mainly the result of the opening of the suture.

- ***Skeletal and dental response***

When the suture is opened the subsequent activation will widen the gap between the left and right part of the maxilla. However, the widening is rarely totally symmetrical, since the nasal septum often deviates to one side, causing asymmetrical resistance. The widening is also uneven in the antero-posterior dimension: it is wider in the front than in the back due to more resistance in the posterior part, caused by the bony attachment of the maxilla to the midface and the partially closed circo-maxillary sutures. Similarly, in the coronal dimension, the maxilla opens as if on a hinge, with its apex at the bridge of the nose.

Since expansion will not only enlarge the palatal arch, but also widen the nasal floor, some changes in breathing pattern are expected to occur. They include amelioration of nasal airway patency and improved phonation (Gray, 1975; McDonald, 1995; Wertz, 1968), changes in pharyngeal microflora (Cazzolla et al., 2006), normalization of sleep architecture and improvement of sleep respiratory pattern (Miano et al., 2009) and may even, as some authors have claimed, reduce enuresis (Eichenberger & Baumgartner, 2014; Schütz-Fransson & Kurol, 2008).

As mentioned earlier, the expansion can take place at a dental or osseous level, and the amount of each is mainly influenced by the type of appliance and the age of the patient. Moreover, some studies have demonstrated that the ratio between dental and bony response might change over time (Proffit, Fields & Sarver, 2007). Inherent forces of overly stretched palatal soft tissue can cause a restriction, and buccally tipped teeth could straighten again. These observations demonstrate the necessity of a certain degree of overcorrection during therapy and an adequate retention period to enable hard- and soft-tissue reorganization.

Even though the appliance is only attached to the maxilla, evidence was given that the lower arch reacted to the movements in the maxilla to some extent (McNamara, Baccetti, Franchi, & Herberger, 2003). These changes in the mandible were mainly observed in transversal tooth distances such as measurements between canines or between first molars. This finding requires further clarification, as it was found that the mandible reacts to the widening of the maxilla even if there is no direct force to the mandible. Possible explanations include dental compensating movements through occlusal forces or an imbalance of tongue and buccal forces owing to the changes based on the widening the maxilla (Baratieri, Alves Jr., Sant'anna, Nojima Mda, & Nojima, 2011; Lima, Lima, Filho, & Oyen, 2004; Lima, Filho & de Oliveira Ruellas, 2007; McNamara et al., 2003).

- ***Rapid palatal expansion – its mechanism***

As mentioned above, rapid palatal expansion was first introduced in 1860 by Emerson C. Angell (1823 to 1903), who was probably the first person to advocate the opening of the median suture to provide space in the maxillary arch (Angell, 1860). Although he postulated from the very onset that the appliance produced enough force to produce a separation of the midpalatal suture, as he was able to observe an opening of the diastema between the central incisive, he nevertheless faced many who discredited and challenged his idea (Timms, 1999).

Expansion protocol nowadays may vary from clinician to clinician, yet certain procedures are agreed upon by many: Rapid palatal expansion (RPE) is usually performed at an opening speed of 0.5 mm a day. RPE typically creates 4000-8000g of pressure across the suture, enough to create microfracture of interdigitating bone spicules in the sutures (Isaacson & Ingram, 1964). A stainless steel hyrax expander device is bonded or banded to as many teeth as possible to absorb the heavy forces, while a different approach is to cement an acrylic RPE device to the teeth.

The effect of such great forces on the dentition remains, even if distributed on many teeth, a justified matter of concern, as heavy root resorption might occur (Akyalcin S, 2015). Hence, many have advocated that it is best to apply RPE devices on primary teeth. This would mean that the optimal age for this appliance is in deciduous or early mixed dentition. In late mixed dentition, the roots of the primary molars do not offer sufficient anchorage to absorb the heavy forces and to pass them on to the alveolar bone. Therefore, in late mixed dentition with deciduous molars which will exfoliate soon, waiting for permanent premolars to erupt and gain enough root length to provide enough anchorage is sometimes inevitable.

With a fixed RPE device it is possible to achieve palatal expansion, even in late mixed dentition. The continuous activation at the jack screw can be done by the patient or by the parents and is considered to be a major advantage (Weyrich et al., 2010) over removable appliances.

2.2. Aim of this study

As mentioned above, claims have been made that changes in the dental arch of the mandible are caused by RPE treatment. This study aims to validate this claim and clarify whether a linear association exists between magnitude of expansion in the maxilla and dental changes in the mandible. In contrast to previous investigations, the methodology of this investigation is broadened and includes not only measurements of distances, but also angles in order to quantify tipping.

3. Material and methods

3.1. Patients

This retrospective study consisted of 28 consecutive patients (18 girls and 10 boys), all treated at the Clinic for orthodontics and paediatric dentistry of the University of Zurich, with a rapid palatal expansion (RPE) between the years 1993 and 2007 according to the clinical protocol described below.

Each patient was examined at two assessment stages: pre-expansion (A1) and post-expansion (A2). (A2) had to be at least 6 months post active expansion.

Written informed consent for secondary use of personal medical data including patients' records and casts was obtained by all patients prior to treatment, according to the directives set by the National Federal Council (Human Research Ordinance (810.301), Art. 30). Ethical guidelines were strictly followed and irreversible anonymization was performed before data analysis, in accordance with State and Federal Law (Human Research Act (810.30), Art. 2 and 32).

3.2. Inclusion criteria

The inclusion criteria were the following: (1) A rapid palatal expansion (RPE) treatment with two or four bands and extension bars. The appliances were cemented and the extension bars were bonded (see Figure 1). (2) No further treatment occurred during the expansion and the observed retention period, the lower arch, in particular, was kept untouched. (3) Complete patient records were available, including an initial plaster cast of the upper and lower arches before treatment (A1) and after retention, prior to insertion of any other further appliance (A2).

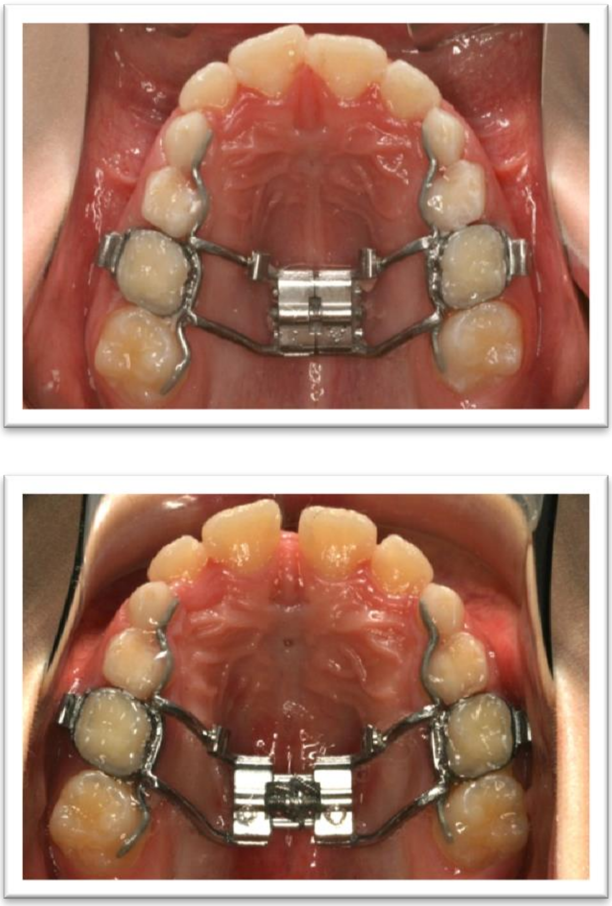

Figure 1: Representative case of the used type of RPE: left before expansion, right after expansion and during retention

3.3. Clinical protocol

All RPE devices were cemented by post-graduate trainees of the Clinic for orthodontics and paediatric dentistry of the University of Zurich. The daily increment of expansion was twice 0.2mm, once in the morning and once in the evening, until overcorrection was achieved. Then the screw was locked with a wire-ligature and the appliance was kept as retention for at least six months. After retention, the appliance was removed and alginate impressions (A2) were taken.

3.4. Cast measurements

Transversal inter-canine and inter-molar (first permanent molars) distances were measured in the upper and lower casts at A1 and compared to the correspondent distances in casts A2 to determine the changes that occurred during the expansion. The inter-canine distance was measured, using the cusps as clearly identifiable measurement-points. For the inter-molar distance in the mandible, the central fossa, in the maxilla the mesio-palatal cusps were used as landmarks (see Figure 2) to assess transversal coordination of upper and lower first molars.

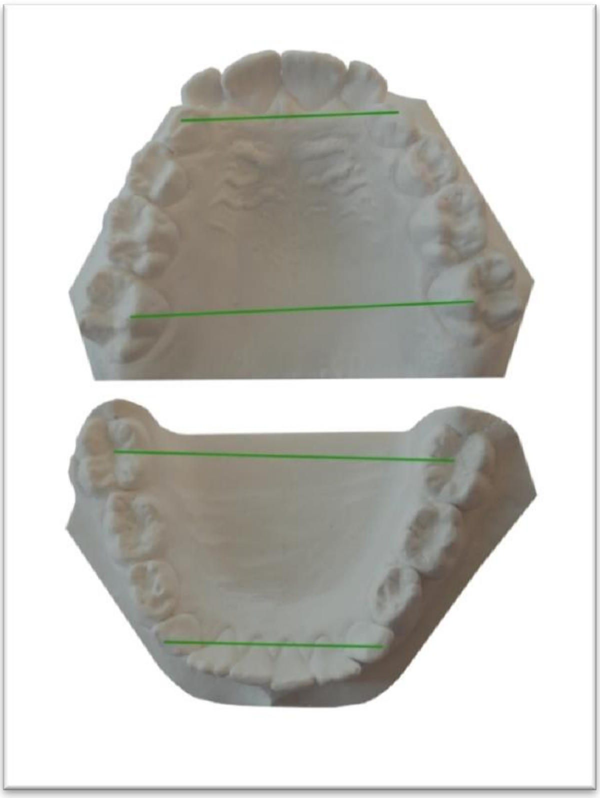

Figure 2: Cast measurements: Green lines correspond to the 4 linear measurements taken on the casts A1 and A2 for every case (4 linear measurements per case in total)

To determine the changes in angle of first molars of the mandible, the casts A1 and A2 were digitalised using an orthodontic scanner ("3shape r700", Great Lakes Orthodontis, LTD). This device allows the scanning of plaster models as well as dental impressions. The cast is mounted into the scanner and automatically digitized. The mount is moved inside the scanner to scan the whole geometry of the plaster model, and the automatic detection of missing areas helps to provide very accurate digital study models.

The digital models were subsequently analysed using the software provided ("3shape Orthoanalyzer 2012-1"). This software allows the viewing of the digitized casts from every direction and also enables the taking of measurements such as distances or angles. It is also possible to define planes by cutting through the casts to produce a cut surface.

On the digitalized casts, the image data were reformatted as a slice through the mesio-buccal cusps of the first molars perpendicular to the occlusal plane (see Figure 3). On the obtained slice, two lines were drawn: the first through the mesiobuccal cusp and the highest point of the mesio-lingual cusp of the left molar and the second line corresponding on the right first Molar (see Figure 4). These two lines produce an angle which was measured for each subject, at A1 and A2.

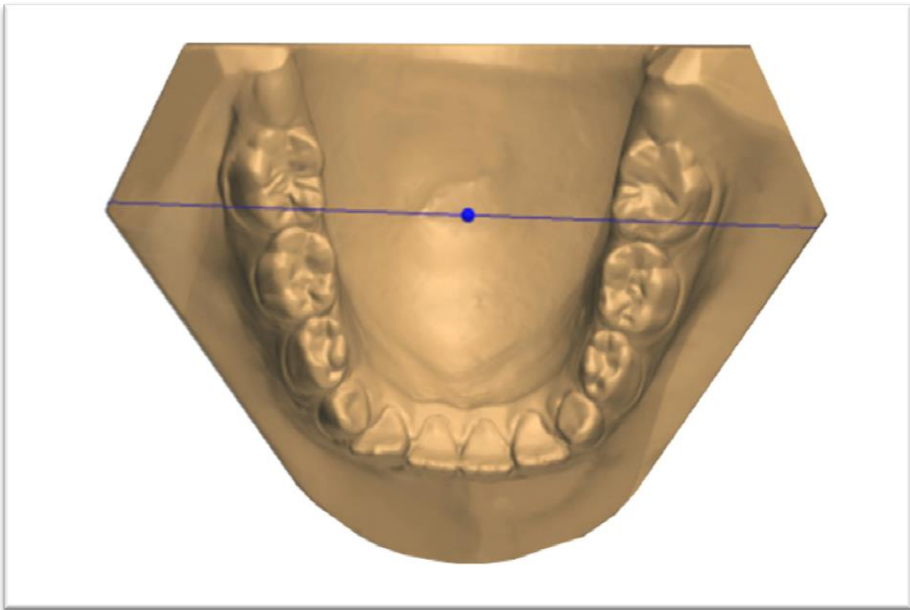

Figure 3: Angle measurement on the digitized casts: blue line corresponds to the defined plane constructed for angle measurements in Figure 4

Figure 4: Angle measurement on the digitized casts: cross-sectional view. Angle between the two red lines was measured

3.5. Statistical analysis

To determine intraobserver reliability, the intraclass correlation coefficient for absolute agreement based on a 1-way random-effects analysis of variance (ANOVA) was calculated for 15 randomly chosen measurements, which were repeated, by the same observer, 6 months apart.

Descriptive statistics for all variables were produced and all variables checked for normal distribution using Kolmogorov Smirnov-test. A paired t-test was applied to assess the difference between A1 and A2 of lower inter-molar and lower inter-canine width as well as lower first molar angle.

The question as to whether the amount of maxillary molar expansion is a valid predictor for the change in mandibular molar width was investigated with a linear regression model, and the adjusted coefficient of determination was used to describe the predictive value of the model. Furthermore, a Pearson correlation was performed to explore a possible association between the observed difference in mandibular molar angle and the difference in mandibular molar width.

4. Results

The intraclass correlation coefficient showed excellent repeatability of the measurements performed on the dental casts (ICC: 0.997, 95% CI: 0.995-0.999), thus demonstrating high reproducibility. This is a requirement for all further analyses.

The sample, which consisted of 28 orthodontic patients (18 females and 10 males), ranged in age between 7 to 15 years, with a mean age at 9.6 years. The canine width could not be identified in all the patients due to missing primary canines or second canines in process of eruption. Therefore, for the upper canine width only 19 patients could be included in the statistical analysis, and similarly only 21 patients for the lower canine width.

All descriptively reviewed variables followed normal distribution and are presented in the tables (Tables 1-5) in the following manner:

- Absolute measurement before treatment (A1)
- Absolute measurement after treatment and at least six months retention (A2)
- Difference between A2 and A1, due to the treatment

Not surprisingly, the greatest difference occurred in the maxilla with inter-molar width increase of 4.97mm and inter-canine width increase of 5.81mm. Subtle differences, however, could also be observed in the mandible. A mean increase in lower molar width of 1.00mm and a change in molar angle of more than 3° were noticed. Conversely, lower canine width remained remarkably constant with just 0.09mm difference before and after treatment.

Accordingly, the paired t-test substantiated the change in lower inter-molar width as highly significant ($p < 0.001$). Similarly, the paired t-test for the lower molar angle was found to be highly significant as well ($p < 0.001$). The very small difference observed in lower canine width was, however, a non-significant change ($p = 0.313$).

Table 1: Upper molar width (n=28)

	Mean (mm)	±1 SD (mm)	Max ; Min (mm)
Before treatment (A1)	42.63	2.36	47.6 ; 37.6
After treatment and retention (A2)	47.60	2.81	53.3 ; 40.9
Difference (A2)-(A1)	4.97	1.76	8.1 ; 1.9

Table 2: Lower molar width (n=28)

	Mean (mm)	±1 SD (mm)	Max ; Min (mm)
Before treatment (A1)	46.70	3.13	54.3 ; 39.7
After treatment and retention (A2)	47.70	2.99	55.5 ; 41.1
Difference (A2)-(A1)	1.00	0.63	2.3 ; 0.0

Table 3: Upper canine width (n=19)

	Mean (mm)	±1 SD (mm)	Max ; Min (mm)
Before treatment (A1)	29.16	2.75	34.0 ; 23.7
After treatment and retention (A2)	34.97	2.70	39.3 ; 29.1
Difference (A2)-(A1)	5.81	2.40	11.3 ;1.6

Table 4: Lower canine width (n=21)

	Mean (mm)	±1 SD (mm)	Max ; Min (mm)
Before treatment (A1)	25.87	1.89	32.3 ; 22.4
After treatment and retention (A2)	25.95	1.90	32.3 ; 22.6
Difference(A2)-(A1)	0.09	0.80	2.6 ; -1.4

Table 5: Molar angle (n=28)

	Mean (°)	±1 SD (°)	Max ; Min (°)
Before treatment (A1)	153.93	12.12	173.7 ; 113.6
After treatment and retention (A2)	157.05	11.08	171.9 ; 124.0
Difference(A2)-(A1)	3.12	4.67	15.2 ; -4.1

Moreover, regression analysis was performed to investigate whether the amount of change in maxillary molar width was associated with the changes occurring in mandibular molar width, and if this could be a predictor of the difference in the lower molar width. The results of the linear regression can be presented in the following equation:

$$\Delta_{\text{Mandibular molar width}} = 1.314 - 0.062 \text{ x } \Delta_{Maxillary\ molar\ width}$$

Although a regression equation can be formulated, the obtained adjusted coefficient of determination R^2 (-0.0062) demonstrates that the predictive value of the regression analysis is extremely low and indicates that future outcomes are not very predictable with the model.

In a last step, a correlation was explored to clarify a possible association between the observed difference in molar angle and the difference in mandibular molar width. The results show a weak negative correlation (corr. coefficient =-0.23) which is non-significant ($p=0.250$). The negative correlation in fact implies that as the expansion in the maxilla increases, mandibular molar angle decreases.

5. Discussion

5.1. Dentoalveolar effects of the rapid palatal expansion (RPE)

The intermolar distance of the upper first permanent molars increased with a mean of 4.97mm while the intercanine distance was raised on average by 5.81mm. This obvious difference may be explained on the basis of the historical landmark findings by Haas (Haas, 1961), who demonstrated that the opening of the midpalatal suture during rapid palatal expansion is not parallel but in a triangular shape. The anterior part of the suture opens by a higher amount compared to the posterior part. The reason for this phenomenon is to be found in the anatomical preconditions of the midface. The maxilla is namely only suturally attached in its posterior part through the palatal bone and the vomer to the sphenoidal bone and to the zygomatic bone, while being cranially connected to the frontal bone. Any applied orthopaedic force in the maxilla will therefore experience more resistance posteriorly, while enabling more reaction anteriorly. It is worthwhile noting that this pattern is contrary to physiological sutural growth at the midpalatal suture, where more growth has been documented posteriorly (Björk & Skieller, 1974).

5.2. Mandibular dentoalveolar adaptation to rapid palatal expansion

As a reaction to the expansion in the maxilla, dentoalveolar adaptation can be expected in the mandible. Several past investigations have indeed reported that an expansion in the maxilla has a noticeable transversal effect on mandible (Haas, 1961; Lima et al., 2004; McNamara et al., 2003).

In general, clinical studies have assessed dental and skeletal effects immediately after RPE, but the amount of relapse following a retention period remains to be clarified. The dentoalveolar relapse in the maxilla has been studied only a few times so far. Hicks reported that retention time impacts the amplitude of relapse. When the appliance was removed right after expansion, a relapse of approximatively 45% of the transverse movement has to be expected. Conversely, 2 to 3 months of fixed retention could reduce the relapse to a rate of 10-23% (Hicks, 1978). In this study we evaluated the mandible after a retention phase of at least 6 months following the active treatment in the maxilla. Since the dentition in the mandible is expected to slowly adapt to the changes provoked by RPE, it is reasonable to assume that these changes only occur during the retention phase, when the overcorrected maxilla forces the mandible into this new occlusion. The expansion phase of the RPE is too fast to induce a dentoalveolar reaction in the mandible, and we assumed, based on the available evidence (Lima et al, 2004), that 6 months are necessary for dental adaptation in the mandible.

5.3. Effect on mandibular intermolar distance and angulation

The main goal of our study was to accurately describe the reaction of the mandible We were able to show that a statistical significant change of intermolar width in the mandible can be observed owing to the expansion of the maxilla, and further that the angle between the left and the right first molar increases significantly as well.

More precisely, we found an increase in the intermolar distance of 1.0mm on average. This is in partial agreement with the literature available on spontaneous dentoalveolar response in the mandible. Lima observed an increase of 0.97mm after 4 months and an additional 0.08mm on average after a longer time of retention in the maxilla, resulting in a mean increase of 1.05mm (Lima, 2004).

Yet Moussa described an increase in mandibular intermolar width of 2.0 mm and a slight additional increase of 0.3 mm after retention (Moussa, O'Reilly, & Close, 1995), and Sandstorm even showed an increase of 2.8 mm (Sandstrom, Klapper & Papaconstantinou, 1988). Although the increase of 1mm was found to be statistically significant, the gain of such a small amount in width has clinically only very little ramification (see below).

5.4. Effect on mandibular intercanine distance

While a statistical increase at the intermolar distance was seen, the intercanine distance remained, surprisingly, very stable. This stability can probably be explained in the following way: while in molars and premolars the lower antagonist will adapt to the new occlusal situation with increased transversal width, the mandibular canine will not be forced to follow the occlusal relief of an antagonist. Furthermore, the observed stability is in accordance with the known fact that intercanine width remains very steady (Morreess et Chadha, 1965; De La Cruz, 1995).

5.5. Amount of changes and clinical significance

The changes in the mandible were small but nevertheless statistically significant where molar width and angulation between the two molars were concerned. The question remains whether these findings are clinically relevant.

Since no transversal increase was observed at the intercanine distance, the clinical impact can be evaluated in the following way (Figure 5): assuming the mesio-distal distance between the canine measurement point and the molar measurement point to be 21mm on average (red line) and the transversal effect of 1mm (blue arrow) to be perpendicular to this line, the increase in the mesio-distal dimension would result in 0.02mm per side (green line: 21.02mm). Hence, we conclude that the statistically significant changes have little clinical significance in terms of gaining space.

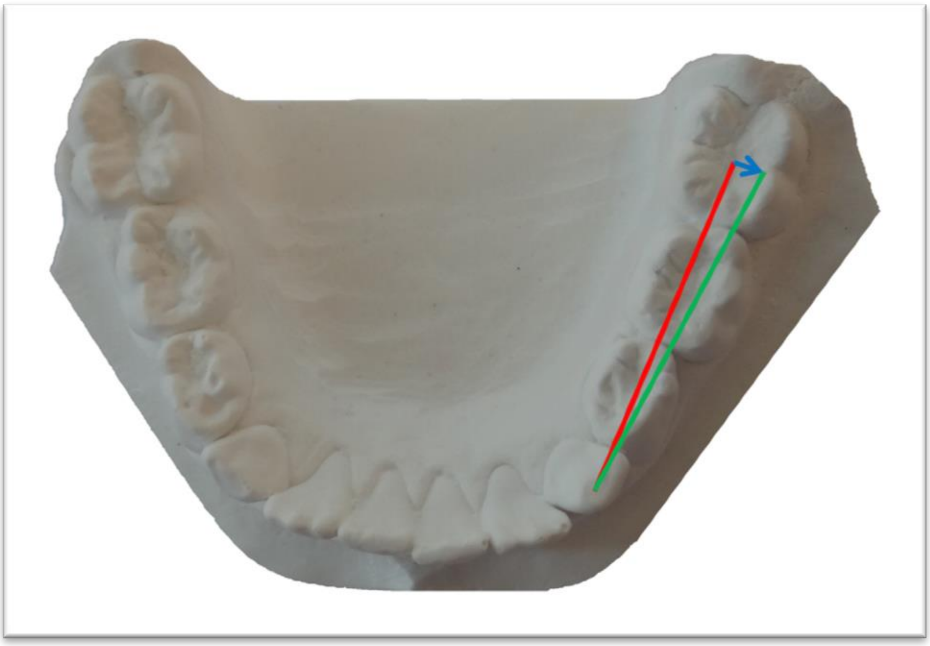

Figure 5: Increase of space due to the lateral movement of the first molar (1mm)

5.6. Interpretation of the changes in molar angulation

Caution should be exercised when interpreting the molar angulation variable, as the buccolingual tip of the lower molar can be different from one side to the other. The molar on the crossbite side in the case of unilateral functional crossbite can be more buccaly tipped than the correspondent molar, due to the different occlusal predisposition to this side. Hence, the angulation registered before treatment might already be subject to asymmetry and the changes occurring as a result of the treatment might also be asymmetrical. Since no stable reference structure in the mandible exists, it is methodologically challenging (if not impossible) to assess the eventuality and degree of asymmetry.

5.7. Predictors for mandibular reaction

We formulated a regression analysis to reveal potential predictors of the dentoalveolar reaction to RPE. The results demonstrate that the amount of expansion in the maxilla is only a very weak predictor for the change of mandibular intermolar width. Thus, although RPE has a statistically noticeable impact on intermolar width, the association between expansion amplitude and mandibular intermolar width increase remains weak and cannot be interpreted as simple cause and effect. Rather, the increase in mandibular intermolar width (and angulation) is most probably the result of multiple etiological factors, such as age, masticatory function, occlusal predisposition, degree of crossbite, initial angulation and many more. Moreover, the assumption of linearity could be challenged, as initial mandibular response to RPE does not necessarily have to correspond to the response in the final steps of RPE. Based on all these reservations, it becomes a necessity to evaluate whether the regression model can be used to predict future outcome.

The adjusted coefficient of determination, a routinely used value to measure how well future data will fit a regression model, was extremely low, indicating that future outcomes are not very predictable with the model.

5.8. Increased width and change in angle of the lower molars

In a last step, a correlation was performed to explore a possible association between changes in intermolar angulation and changes in intermolar width. The results are non-significant, implying that changes in angulation are not associated with changes in intermolar width. It could thus be hypothesized that two reaction mechanisms to RPE can separately occur: the molars could either predominantly tilt (increasing the angulation), or bodily move (increasing the width). Although both reactions are most probably not mutually exclusive, a differentiation between the two could possibly explain the negative correlation coefficient.

5.9. Comparison to other studies

Remarks on comparable research have already been included above concerning the intermolar width. As mentioned in the introduction, to the best of our knowledge no research has been performed to evaluate changes in the angulation of the molars. In a recent study, Santos described the change of intermolar width in patients receiving a RPE compared to a control group, using the lingual sulcus as measurement points on the molars (Santos et al., 2010). He could not find a significant increase in the lower molar distance. We on the other hand used the central fossae as measurement points, which could explain the difference as described below.

Lima and co-authors worked with a similar sample size but analysed at more different stages, described as: pre expansion, short term follow up, progress and long term follow up (Lima et al., 2004). As mentioned above, they similarly found a slight increase in lower intermolar width between pre expansion and short term follow up. They measured at two sites: the occlusal parameter showed a mean increase of 1.47mm, the lingual parameter was only increased in average by 0.97mm. While they did not discuss that fact any further, our study could potentially provide an important contribution to the understanding of this differential movement, which is probably best interpreted as up-righting of the molars, as we noticed that not only intermolar width increases, but that intermolar angulation is also significantly affected.

Ghoneima (Ghoneima et al., 2010) investigated the transversal effects of RPE using 3D tomographic images and found an increase of 1.7mm for intermolar width of the mandibular first molars. It remains, however, open for discussion if the observations of Ghoneima can be compared to our findings, owing to the different methodological approaches, i.e. tomographic imaging versus plaster moulds and different parameters used.

5.10. Limitations

One main constraint in describing dentoalveolar changes in the mandible is the evident lack of a stable reference structure. In the maxilla the palatal median raphe is commonly used as a relatively stable structure with little change over time, but there is nothing comparable in the mandible. Furthermore, in our case it was likewise impossible to use teeth as a stable structure, since these were used as outcome values. We would not expect changes in the lower front teeth due to the changes in the maxilla, but nevertheless this would be considered a methodological flaw if used as a stable structure in our patients. During this period of development vertical changes at the incisors are to be expected, not only during the transition stage from primary to secondary teeth, but also throughout craniofacial growth. Moreover, it was recently shown that the antero-posterior angulation of incisors is subject to minor changes throughout childhood and adolescence (Gütermann et al., 2012).

The low number of cases might also be considered a limitation. In retrieving applicable cases, we aimed to gather a sample of comparable individuals, and concentrated on patients who only received a RPE and no other treatment simultaneously. A lot of patients thus had to be excluded, since they were wearing a headgear during retention phase, which could potentially have an influence. These patients along with those who received fixed or other appliances had to be disregarded. Yet, in our defence it must be stated that the sample size was large enough to carry out statistical testing and obtain significant results and several other investigation in this field have worked with similar sample sizes.

Finally, the lack of a control group could be identified as a further limitation. It is true that some significant changes occurred during the observation period, yet these shifts do not necessarily represent a response to RPE, but could theoretically also be physiological changes that would likewise have ensued in untreated subjects. Epidemiological data of Sillman's longitudinal landmark study on dimensional changes of the dental arches demonstrate that very little transversal modification is to be expected during physiological growth (Sillman, 1964). Thus, it can be assumed that the observed significant changes portray the effects of the therapy investigated.

6. Literature

(alphabetical)

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